

Accuracy of Temporal Artery Thermometry in Neonatal Intensive Care Infants

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ABSTRACT

Purpose: To determine the accuracy of temporal artery and axillary temperatures and the discomfort level of stable neonates during temperature measurement.

Subjects: Convenience sample of neonates between the ages of 32 and 40 weeks' gestation cared for in an isolette or crib.

Design: A method-comparison design was used to compare different methods for noninvasive temperature monitoring (infra-red temporal artery; axillary electronic) to core body temperatures (indwelling rectal probe).

Main Outcome Measure: Bias and precision of test temperature devices (temporal artery; axillary).

Results: Bias and precision for the temporal artery and axillary devices were 0.30 ± 0.44 and 0.28 ± 0.33 , respectively. Analysis of variance found significant differences between both temporal and axillary temperatures compared to rectal temperatures ($P < .01$). Statistical differences were small and did not represent a clinically important difference. No statistical difference was found between temporal artery and axillary temperatures ($P = .81$). Increases in neonate discomfort after temperature measurement were significantly greater with axillary than increases after temporal artery temperature measurement ($P = .03$).

Conclusions: This study found that body temperature measured with the temporal artery thermometer was similar to temperatures obtained with an axillary thermometer in stable, afebrile neonates. The use of temporal artery thermometry appears to be an acceptable approach for noninvasive temperature measurement in neonates, which causes less discomfort in neonates.

KEY WORDS: axillary temperature, core temperature, neonates, rectal temperature, temporal artery temperature

The monitoring of temperature in hospitalized patients is important for the early identification of complications and to guide medical interventions. In critically ill neonates, the importance is magnified because of the high incidence of ther-

moregulatory problems in this population of premature infants.¹ Accuracy of the device for temperature monitoring is essential to maximize quality care to this vulnerable patient population.

The most common sites and methods used clinically for temperature monitoring in the neonatal intensive care unit (NICU) are axillary temperatures measured with an electronic thermometer (Figure 1A) and skin temperatures measured with thermistors that are connected to an overhead warmer or an isolette. Well-designed clinical studies, though, have found large discrepancies between skin temperatures and more direct measures of core body temperature (esophageal or rectal sites using electronic thermistor devices).²⁻⁴ Axillary temperatures measured with an electronic thermometer probe, while previously shown to have acceptable accuracy in neonates and newborns,⁵⁻¹¹ are difficult to obtain without disturbing the neonate. These disturbances can cause increases

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in respiratory rates and heart rates, with decreases in oxygen saturation levels, circumstances that are best avoided in critically ill neonates.

Recently, a noninvasive infrared tympanic thermometer device was altered to allow temperature monitoring by sweeping the infrared device across the forehead and temporal artery (Figure 1B).^{12,13} The temporal artery thermometer uses a scanner probe to detect thermal radiation emitted from the skin under the sensor, displaying the highest temperature measured. This displayed temperature is actually a calculated temperature based on a proprietary algorithm used to compensate for ambient temperatures that are measured as well by the device.^{12,14} Clinical studies of the temporal artery device in children and adults found the device to be more accurate than tympanic and/or axillary temperature devices.¹⁴⁻²⁷ To date, no published data were located that examined the accuracy of the temporal artery device in neonates. If accurate, the unencumbered accessibility of the forehead for temperature monitoring would make this a

preferred way to monitor noninvasive temperature in neonates rather than the axillary method.

The primary purpose of this study was to determine the accuracy of the temporal artery thermometer in neonates including the bias and precision of test temperature devices (temporal artery; axillary).

An additional purpose was to determine the discomfort associated with temperature measurement with both the temporal artery and axillary thermometers.

MATERIALS AND METHODS

This study was conducted in a level IIIa NICU in a not-for-profit hospital in the Western United States. Prior to data collection, review and approval of the study were obtained from the investigational review board of the health system. Informed consent was obtained from a parent of the neonate.

Study Design

A method-comparison study design was used to evaluate the level of agreement between 2 test thermometers (temporal artery; axillary) and the reference standard thermometer (indwelling rectal). Each subject served as his or her own control and was randomly assigned to the order of temperature measurement (temporal artery or axillary first) using a computer-generated random number sequencer. The primary dependent variable was the difference in temperature calculated by subtracting the reference temperature value from the test temperature value. A secondary variable was the change in discomfort scores associated with temperature measurement.

Sample Selection

Subjects for this study were neonates in the NICU with gestational age between 32 and 40 weeks at birth who were being cared for in an isolette or crib. Exclusion criteria included the following: requirement of a radiant warmer; presence of tape on the forehead or temporal area or a bilirubin mask; fractured clavicle; neonatal pain scale score greater than 6; any rectal abnormalities; and/or antipyretic medication administration within 4 hours.

The calculated sample size for this study was a minimum of 33 subjects. Sample size was determined with power analysis for analysis of variance (1 between factor, 1 within factor) with a power of 0.8, an alpha level of .05, and an effect size of 0.50.^{28,29} Effect size was calculated using a standard effect size formula (effect size = $[\text{mean}_{\text{groupA}} - \text{mean}_{\text{groupB}}]/\text{SD}$)²⁹ and was based on clinical judgment that differences between the test temperature devices (temporal; axillary) and the rectal temperature of greater than 0.5°C would limit the clinical utility of that device for temperature measurement and clinical decision-making surrounding temperature management of the neonate. Standard deviation data for the sample size calculation

FIGURE 1.



Different methods for monitoring body temperature in neonates: A. Axillary temperature measurements with an electronic thermometer; B. Temporal artery temperature measurement with an infrared thermometer.

(SD = 0.9) were estimated from previous studies of temperature devices in children.^{17,18}

Instruments

The following devices or scales were used in this study:

1. *Rectal temperature (reference standard).* A 9 Fr, level 1 Esophageal/Rectal Temperature Probe (Smiths Medical ASD, Inc, Rockland, Massachusetts), with a thermistor equivalent to YSI 400 series and connected to a DASH 5000 cardiac monitor (GE Health care, Waukesha, Wisconsin) for digital display of the temperature. Device accuracy reported by the manufacturer is less than ±0.1°C. Temperatures were obtained according to manufacturers’ guidelines in the monitor mode (Table 1).
2. *Temporal artery temperature (test device).* An infra-red, electronic temperature device (Model #TAT 5000, Exergen, Watertown, Massachusetts), which is moved across the forehead area according to the manufacturer’s directions (Table 1). Device accuracy reported by the manufacturer is less than ±0.1°C.
3. *Axillary temperature (test device).* An electronic temperature device (Welch-Allyn Sure Temp Plus, Model 692 Thermometer, Welch Allyn, Inc, San Diego, California) placed in the axillary mode with the probe inserted into the axillary fold according to the manufacturer’s directions (Table 1). Device accuracy reported by the manufacturer is less than ±0.1°C.
4. *Infant Discomfort Scale.* A behavior assessment scale with 5 levels ranging from drowsy/asleep to agitated (Table 2).^{18,30}

Higher scores represent greater discomfort. The Infant Discomfort Scale has been primarily used in emergency departments and on older infants. Reliability and validity of this scale in neonates have not been established.

Procedure

Prior to data collection, study investigators were trained in all study-related procedures (proper use of temperature devices; scoring of behavior with the Infant Distress Scale; provision of informed consent). Biomedical engineering at the study site validated the performance of all temperature devices and equipment within manufacturers’ specifications prior to data collection.

Following parental consent, an indwelling rectal thermometer probe was inserted by a neonatal nurse practitioner using standard procedures (Table 1). At least 5 minutes after insertion of the rectal probe, at a time when temperature measurement was required for usual clinical care, axillary and temporal artery temperatures were obtained according to the manufacturer’s directions (Table 1). The order of temporal artery and axillary temperature measurements was randomly assigned by computer. A period of less than 2 minutes occurred between the sequential temperature measurements.

Before and after the temporal and axillary temperature measurements, rectal temperature was recorded. The subject was rated with the Infant Discomfort Scale before and after temporal and axillary temperature measurements (Table 2).

TABLE 1. Procedure Used for Obtaining Rectal, Temporal Artery, and Axillary Temperatures in Neonates

<p>Rectal temperature measurement</p> <ol style="list-style-type: none"> 1. Lubricate and gently insert the disposable rectal probe to 5 cm. If resistance is felt during insertion, withdraw probe immediately. 2. Following at least a 5-min equilibration period, record the rectal temperature from the DASH 5000 GE Medical Systems Technologies cardiac monitor in degree centigrade. <p>Axillary temperature measurement</p> <ol style="list-style-type: none"> 1. Gently lift the neonate’s arm so that the entire axilla is easily observed and insert the covered probe tip of the electronic thermometer as high as possible in the axilla with the tip directly in the skin folds. Verify that the probe tip is completely surrounded by axillary tissue and place the arm snugly at the patient’s side. Be sure that there is not any clothing, monitor leads, or vernix in contact with the probe. Hold the patient’s arm in this position and do not allow movement of the arm or probe during the measurement cycle. 2. The unit will beep 3 times when the final temperature is reached. Record the axillary temperature in degree centigrade and remove the probe from the patient’s axilla. <p>Temporal artery temperature measurement</p> <ol style="list-style-type: none"> 1. Brush the neonate’s hair aside if covering temporal area 2. Depress button to turn on thermometer 3. With probe flush on center of forehead, depress and hold the button while slowly sliding the probe straight across the forehead to the location of the temporal artery (midline about 2 mm below the surface of the skin along the hair line). 4. Release the button and record the temporal artery temperature in degree centigrade

TABLE 2. Adapted Infant Discomfort Scale

Score	Description of Behavior
1—Drowsy/asleep	Eyes closed, may respond to stimulation
2—Relaxed	Lying with eyes open, accepts intervention readily
3—Anxious	Verbal and nonverbal signals observed, accepts comfort measures and intervention reluctantly
4—Upset	Crying, nonverbal cues of over stimulation exhibited, considerable effort required to achieve compliance with intervention
5—Agitated	General loud or high-pitched crying, requires physical restraint, strongly refuses intervention

From Greenes and Fleisher¹⁸ and Shane et al.³⁰

Data Analysis

Data were summarized using descriptive statistics (range, mean, SD, percentiles). Bias and precision were calculated to quantify the differences between the test and reference standard temperatures.^{31,32} Test temperature device values (temporal artery; axillary) were compared with reference standard temperature device values (rectal temperature obtained immediately after test device temperatures) according to the method of Bland and Altman.³¹⁻³⁴ Analysis of variance was used to determine whether differences between test and reference standard temperature devices were significant and/or whether the order of device testing effected temperature differences. The Bonferroni multiple comparison test was used for post hoc testing between groups. Chi-square analysis was used to determine whether changes in discomfort scores after temperature measurement were different between the temporal artery and axillary methods. The level of significance for all tests was $P < .05$.

RESULTS

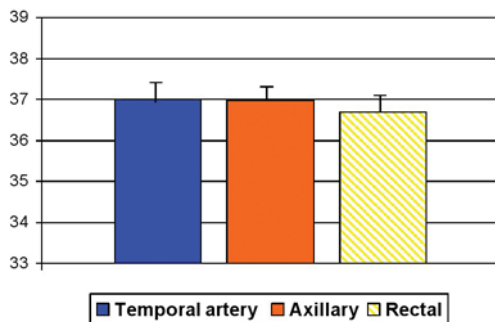
A total of 34 subjects (18 males and 16 females) were studied. Patient characteristics are presented in Table 3. Ages of the subjects ranged from 32 to 40 weeks with

an average age of 35.7 ± 1.8 (\pm SD) weeks. There were no statistical differences between the 2 groups related to gender or gestational age. Temperatures ranged from 35.9°C to 37.2°C , with an average of $36.7^{\circ}\text{C} \pm 0.38^{\circ}\text{C}$ (Table 3). Changes in rectal temperature from before and after temperature measurement with the test devices averaged $0.02^{\circ}\text{C} \pm 0.06^{\circ}\text{C}$, with 32 of the 34 subjects exhibiting temperature changes of 0.1°C or less. Two subjects had a 0.2°C change in rectal temperature during data collection.

Average (\pm SD) values for temperatures with the 3 temperature devices are summarized in Table 4 and Figure 2. Table 4 and Figure 3 graph displays the difference scores for each subject between the temporal artery and the reference standard device (rectal temperature), as well as the bias (average temperature difference between test and rectal devices) and precision (\pm SD for temperature difference scores) for those devices. Average temperature differences (bias) \pm SD (precision) for the test thermometers (temporal artery; axillary) compared to the reference standard (rectal) thermometer were $0.30^{\circ}\text{C} \pm 0.44^{\circ}\text{C}$ for the temporal artery device and $0.28^{\circ}\text{C} \pm 0.33^{\circ}\text{C}$ for the axillary device (Figure 3; Table 4). The percentage of subjects who had more than 0.5°C differences

TABLE 3. Demographic and Baseline Data for 34 Neonates Randomly Assigned to 2 Different Sequences for Temperature Measurement With the Temporal Artery and Axillary Temperature Devices. (A) Group 1 (Temporal Artery and Axillary) and (B) Group 2 (Axillary: Temporal Artery)

	Subjects		
	Combined (N = 34)	Group 1 (N = 18)	Group 2 (N = 16)
Gender			
Male	18 (53%)	10 (59%)	8 (47%)
Female	16 (47%)	7 (41%)	9 (53%)
Age (weeks gestation at birth), mean \pm SD	35.7 ± 1.8	36.0 ± 1.8	35.3 ± 1.7
Rectal temperatures (degrees C), mean \pm SD	36.7 ± 0.38	36.7 ± 0.38	36.6 ± 0.37

FIGURE 2.

Comparison of average $9(\pm SD)$ temperatures measured with 3 different devices (temporal artery, axillary, rectal) in 34 stable, afebrile neonates.

between the test thermometer and the reference standard thermometer was 27% ($n = 9$) for the temporal artery device and 18% ($n = 6$) for the axillary device. The percentage of subjects who had 1.0°C or more difference between the test thermometers and the rectal reference standard thermometer were 6% ($n = 2$) for the temporal artery device and 3% ($n = 1$) for the axillary device.

Significant differences were found between the temperature devices ($F_{2,95} = 7.69$, $P < .008$) but not for the order of temperature device testing ($F_{1,95} = 0.43$, $P = .84$). Multiple comparison testing found a significant difference in temperature between the temporal artery and rectal temperature devices ($P = .0007$) and the axillary and rectal temperature devices ($P = .0016$). No statistical significant difference was found between the temporal artery and axillary temperatures ($P = .81$). Post hoc power analysis for repeated-measures analysis of variance found power of the study to be more than 0.90.²⁹

Discomfort scores before each of the temperature measurements were low, with all but 1 subject scoring a 1 (drowsy) or 2 (relaxed). Discomfort scores after temperature measurement were higher in 3 neonates (9%) with the temporal artery device than baseline scores, with 14 neonates (41%) having higher discomfort scores after axillary temperature measurement (Table 5). The majority of discomfort scores for the neonates were unchanged during both temperature measurements (82% for temporal artery; 53% for axillary). Chi-square analysis found a significant difference in the discomfort score changes between the 2 temperature devices ($\chi^2 = 10.7$, $df = 4$, $P = .03$).

DISCUSSION

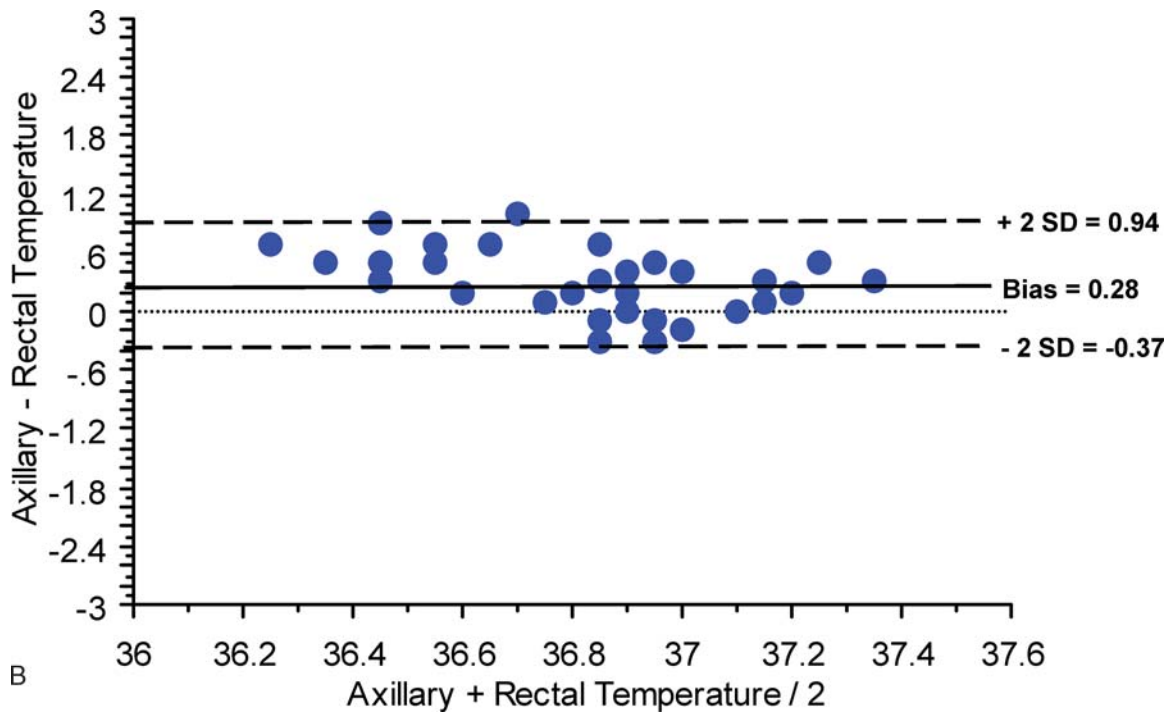
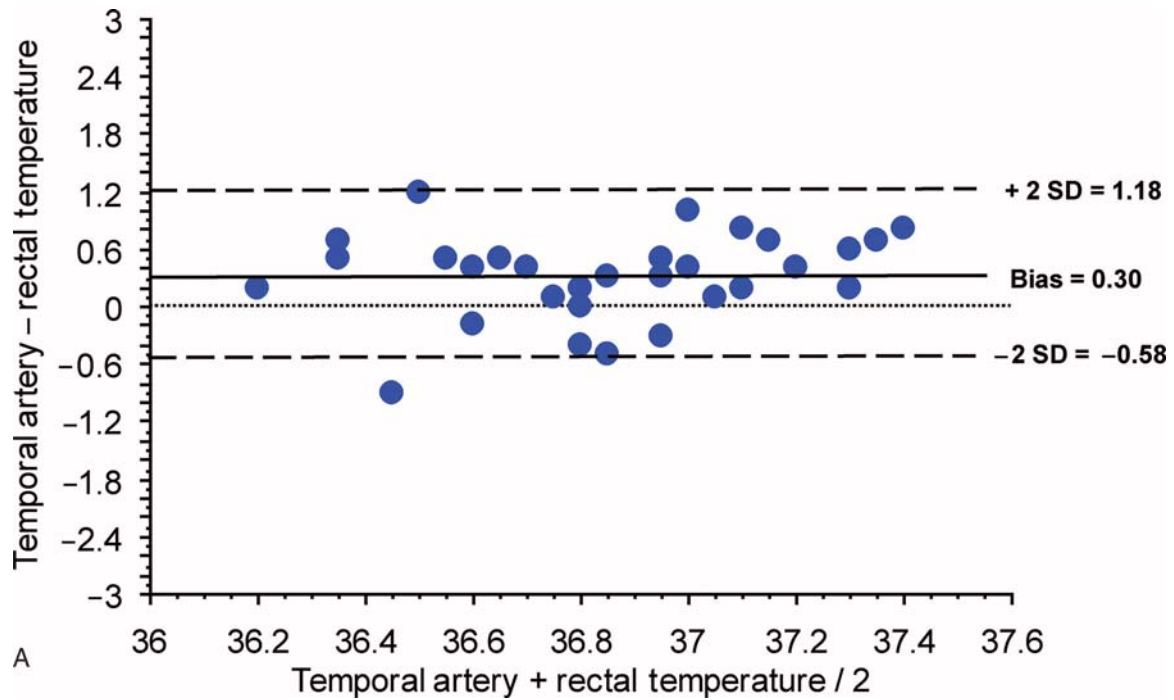
This is the first clinical study to evaluate the accuracy of temporal artery thermometry in the neonatal population. We found that temperatures measured with

a temporal artery thermometer were statistically different from an indwelling rectal probe temperature. The clinical significance, though, of this temperature difference is best appreciated by evaluation of the bias and precision of the temporal artery temperature device displayed in the Bland-Altman graph (Figure 3A). Bias refers to any influence that may produce a distortion in the results of the study. Precision refers to the reliability of the results. The bias value for the temporal artery device was close to 0.0 and represents clinically insignificant differences between the devices and rectal temperatures. Precision values for both devices were within the acceptable range of $\pm 0.5^{\circ}\text{C}$ or less often cited by experts^{14,22,35,36} or used in other temperature research studies as necessary for clinical use of a temperature device as a surrogate for a core temperature measured with an invasive temperature device. Since the bias and precision values observed in this study for the temporal artery temperature device were small and/or within acceptable ranges, these data support the use of temporal artery temperatures for estimating core temperatures in stable, nonfebrile neonates.

While this is the first study to evaluate the accuracy of temporal artery thermometry in neonates, prior studies in infants younger than 24 months^{17,20,27} and children²³ found similarly small biases and acceptable precisions for the temporal artery temperature device. Similar to our findings, one of the studies found a positive bias, reflecting a higher temporal artery value than rectal temperatures,²⁰ whereas some studies found lower bias values (temporal artery temperatures lower than rectal).^{17,27} In adults, several studies have also found the bias of the temporal artery device to be higher than the core device, particularly in normothermic body temperatures.^{12,37,38} Since all of the temporal artery temperature devices used in this and prior studies were made by the same manufacturer, calibrated prior to data collection, and allowed to equilibrate with the ambient temperature in the islette prior to use, the most likely explanation for the variation in bias values is the small bias values and their proximity to zero. The difference between a negative or positive bias could easily be due to a few additional positive or negative values for individual subjects in one study compared to another. Another possible explanation is that the manufacturer's proprietary algorithm for adjusting the measured temperature prior to digital display is overcorrecting temperatures to reflect core temperatures.

This study also found that axillary temperatures were statistically different from indwelling rectal probe temperatures. Axillary bias and precision values, as well as Bland-Altman graphed data, were similar to our findings with the temporal artery and rectal temperature devices. Again, while the axillary temperatures were statistically different from rectal temperatures, these differences were small and not clinically important. Prior comparisons of axillary

FIGURE 3.



Bland-Altman plots of temperature differences (average difference=bias) and limits of agreement (\pm SD) in degree Celsius between the rectal reference standard temperature device and the temporal artery (A) and axillary (B) temperature devices in 34 stable, afebrile neonates.

and rectal temperatures have found the smallest differences in infants (usually 0.2°C),^{5,9,11,39,40} with differences increasing as age increases to adulthood (from 0.5°C to 1.2°C).^{22,41-45} While axillary temperatures

are not recommended in children and adults as an accurate reflection of core temperatures,^{39,46} use in neonates and newborn infants is clinically recommended since axillary bias and precision values

TABLE 4. Temperatures in Degrees Centigrade for Test Temperature Devices (Temporal Artery, Axillary) and Rectal Temperature Device in 34 Stable, Afebrile Neonates

	All Temperatures*	Test Device–Rectal Temperature ^a Bias ± Precision	Number Temperatures >0.5°C	Number Temperatures ≥1.0°C
Temporal artery	37.0 ± 0.41	0.30 ± 0.44	9 (27%)	2 (6%)
Axillary	37.0 ± 0.24	0.28 ± 0.33	6 (18%)	1 (3%)
Rectal	36.7 ± 0.37			

*Mean ± SD.

found in other studies,^{5-9,11,37,39,46,47} similar to our study, were small and clinically insignificant.

Despite acceptable bias and precision values for both the temporal and axillary temperature devices, 25% of temporal artery, and almost 20% of axillary, temperatures obtained were more than $\pm 0.5^{\circ}\text{C}$ different from the rectal device. These data emphasize that not all temperatures obtained with these devices will be within an acceptable range of variation. Clinically, the temperatures obtained with either the axillary or temporal artery device must be evaluated within the context of the clinical situation. When other clinical information is in disagreement with noninvasive temperature values, clinicians should be cautious of accepting these temperature readings and consider repeating the temperature measurement and/or use an invasive method for temperature measurement (eg, rectal temperatures).

Because axillary temperatures are used in many NICUs for monitoring of body temperatures in stable neonates, we were interested in determining whether temperatures measured with temporal artery thermometry would eliminate or decrease some of the inevitable discomforts that occur for the neonate during axillary temperature monitoring. By observing the neonate's behaviors before and after the use of each temperature device measurement, we found that a large number (41%) of neonates experienced behaviors associated with discomfort with axillary temperature measurement but not with temporal artery measurement (only 9%). The only prior study to evaluate

discomfort with temperature measurement in hospitalized subjects found that infants had low scores of discomfort with temporal artery temperature measurement,¹⁸ similar to our findings in neonates. Given the statistical equivalence found in this study between the axillary and temporal artery temperatures, clinical use of the temporal artery thermometer may be a way to decrease some of the discomfort to neonates associated with temperature monitoring without decreasing the accuracy of temperature measurement when axillary temperatures are the standard for the NICU.

Similar to findings in this study with the temporal artery device, axillary average temperatures were slightly higher than rectal temperatures. While most prior studies of axillary temperature devices in neonates or infants that were compared with core temperature devices found the opposite result, several studies had similar findings to ours.^{11,20,47} Explanations for this result with axillary devices are similar to those previously discussed for the temporal artery results.

Limitations

It is important to note that the temperatures assessed in this study were almost all in the normothermic range, with no temperatures more than 37.5°C and very few temperatures less than 36.5°C . The accuracy of the temporal artery thermometer in neonates with abnormal body temperatures is not known and additional studies are needed to validate the accuracy of the device in these conditions. Prior studies evaluating the temporal artery thermometer found that the

TABLE 5. Changes in Discomfort Scores After Temporal Artery and Axillary Temperature Measurements in 34 Neonates

	Change in Discomfort Score	Temporal Artery (N = 34)	Axillary (N = 33)
Less discomfort	-1	3	1
Same discomfort	0	28	18
More discomfort	+1	1	5
	+2	1	7
	+3	1	2

discrepancies between the temporal artery and invasive, core temperatures were greater in febrile subjects than in normothermic study subjects.^{17,23,37}

Another limitation of this study is that we did not restrict the measurement of temperatures to just 1 or 2 investigators (7 investigators measured temperatures), a common method used in many prior temperature studies to improve accuracy with the device. This approach was purposefully taken to better reflect the measurement error that could typically occur in actual clinical practice situations. Since temperatures for all neonates in an NICU are not routinely obtained by a single individual, we felt that it was important to determine the device performance under more typical clinical user conditions. This attempt to approximate clinical conditions, though, did not completely reflect usual practice since many more than 7 different individuals obtain temperatures in an NICU each day. We did not formally test interrater reliability. However, when investigators were trained to use the devices and Discomfort Scale, they practiced until they obtained the same consistent results. Larger bias and precision values may be found in actual clinical practice situations with larger numbers of clinical users than was found in this study.

Another limitation is that the study evaluated only infants between the ages of 32 and 37 weeks' gestation who were being cared for in an open crib or isolette. Whether similar results would occur in younger infants or those in warmers is not known. The Infant Discomfort Scale is also a limitation because of the lack of established reliability and validity on neonates in an NICU. In addition, further research needs to be done using preterm infants at less than 32 weeks' gestation.

Clinical Implications

Based on the findings of this study, the use of the temporal artery thermometer in stable, normothermic neonates appears to be a clinically reasonable alternative to axillary temperature measurement. The statistical equivalency of the temporal artery and axillary temperatures, coupled with less discomfort to the neonate during temporal artery device use, makes the temporal artery thermometer an attractive alternative for temperature monitoring in neonates.

CONCLUSIONS

This study found that body temperature measured with the temporal artery thermometer is similar to temperatures obtained with an axillary thermometer in stable, afebrile neonates. While both temperatures were statistically different from invasive, core temperatures, the differences were within the standards set for noninvasive temperature measurement. Neonates experienced less discomfort with the temporal artery thermometer than with axillary thermometer method.

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References

- Martin R, Fanaroff A, Walsh M. *Neonatal Perinatal Medicine Diseases of the Fetus and Infant*. 8th ed. Philadelphia, PA: CV Mosby; 2006.
- LeBlanc M. Skin, rectal or air temperature control in the neonate: which is the preferred method? *J Perinatol*. 1985;5(2):2-7.
- Dollberg S, Atherton HD, Sigda M, Acree CM, Hoath SB. Effects of insulated skin probes to increase skin-to-environmental temperature gradients of preterm infants cared for in convective incubators. *J Pediatr*. 1994;124:799-801.
- Krause B. Accuracy and response time comparisons of four skin temperature-monitoring devices. *Nurse Anesth*. 1993;4(2):55-61.
- Blitz-Holtz J. Comparison of rectal, axillary, and inguinal temperatures in full-term infants. *Nurs Res*. 1989;38(2):85-87.
- Haddock B, Vincent P, Merrow D. Axillary and rectal temperatures of full-term neonates. Are they different? *Neonatal Netw*. 1986;5(1):36-40.
- Haddock B, Merrow D, Vincent P. Comparisons of axillary and rectal temperatures in preterm infant. *Neonatal Netw*. 1988;6(5):67-71.
- Mayfield S, Bhatia F, Nakamura K, Rios G, Bell E. Temperature measurements in term and preterm neonates. *J Pediatr*. 1984;104:271-275.
- Kunzel M, O'Brien C, Munro BH, Medoff-Cooper B. Comparison of rectal, femoral, axillary and skin-to-mattress temperatures in stable neonates. *Nurs Res*. 1988;37(3):162-164.
- Schiffman R. Temperature monitoring in the neonate: a comparison of axillary and rectal temperatures. *Nurs Res*. 1982;31:274-277.
- Cussons R, Madonia J, Tackman J. The effect of environment on body temperature in full term neonates. *Nurs Res*. 1997;46:202-207.
- Kistemaker J, Den Hartog E, Daanen H. Reliability of an infrared forehead skin thermometer for core temperature measurements. *J Med Engin Tech*. 2006;30:252-261.
- Sandlin D. New product review: temporal artery thermometry. *J Perianesth Nurs*. 2003;18:419-421.
- Kimberger O, Cohen D, Illievich U, Lenhardt R. Temporal artery versus bladder thermometry during perioperative and intensive care unit monitoring. *Anesth Analg*. 2007;105:1042-1047.
- Roy S, Powell K, Gerson L. Temporal artery temperature measurements in healthy infants, children, and adolescents. *Clin Pediatr*. 2003;42(5):433-446.
- Frommelt T, Ott C, Hays V. Accuracy of different devices to measure temperature. *Med Surg Nurs*. 2008;171-174, 176, 182.
- Hebbar K, Fortenberry J, Rogers K, Merritt R, Easley K. Comparison of temporal artery thermometer to standard temperature measurements in pediatric intensive care unit patients. *Pediatr Crit Care Med*. 2005;6:557-561.
- Greenes D, Fleisher G. Accuracy of a noninvasive temporal artery thermometer for use in infants. *Arch Ped Adol Med*. 2001;155:376-381.
- Callanan D. Detecting fever in young infants: reliability of perceived, pacifier, and temporal artery temperatures in infants younger than 3 months of age. *Pediatr Emerg Care*. 2003;19:240-243.
- Schuh S, Komar L, Stephens D, Chu L, Read S, Allen U. Comparison of the temporal artery and rectal thermometry in children in the emergency department. *Pediatr Emerg Care*. 2004;20:736-741.
- Marable K, Shaffer LE, Dizon V, Opalek JM. Temporal artery scanning falls short as a secondary, noninvasive thermometry method for trauma patients. *J Trauma Nurs*. 2009;16(1):41-47.
- Lawson L, Bridges EJ, Ballou I, et al. Accuracy and precision of noninvasive temperature measurement in adult intensive care patients. *Am J Crit Care*. 2007;16:485-496.
- Suleman M, Doufas A, Akca O, Ducharme M, Sessler D. Insufficiency in a new temporal-artery thermometer for adult and pediatric patients. *Anesth Analg*. 2002;67-71.
- Titus M, Hulsey T, Heckman J, Losek J. Temporal artery thermometry utilization in pediatric emergency care. *Clin Pediatr*. 2009;48:190-193.
- Fetzer SJ, Lawrence A. Tympanic membrane versus temporal artery temperatures of adult perianesthesia patients. *J Perianesth Nurs*. 2008;23:230-236.
- Langham G, Maheshwari A, Contrera K, You J, Mascha E, Sessler D. Noninvasive temperature monitoring in postanesthesia care units. *Anesthesiology*. 2009;111:90-96.
- Sidberry G, Keiner-West M, Schappell E, Karron R. Comparison of temple temperatures in children under two years of age. *Clin Pediatr*. 2002;41:405-414.
- Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. Rev ed. New York, NY: Academic Press; 1977:313.
- Faul F, Erdfelder E. GPOWER: a priori, post-hoc, and compromise power analysis for MS-DOS. <http://www.psych.uni-duesseldorf.de/aap/projects/gpower/>. Accessed December 15, 2010.
- Shane S, Fuchs S, Khine H. Efficacy of rectal midazolam for the sedation of preschool children undergoing laceration repair. *Ann Emerg Med*. 1994;24:1065-1073.
- Hanneman SK. Design, analysis and interpretation of method-comparison studies. *AACN Adv Crit Care*. 2008;19:223-234.
- Szaflarski N, Slaughter R. Technology assessment in critical care: understanding statistical analyses used to assess agreement between methods of clinical measurement. *Am J Crit Care*. 1996;5:207-216.

33. Bland J, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1:307-310.
34. Chatburn R. Evaluation of instrument error and method of agreement. *J Am Assoc Nurse Anesth*. 1996;64:261-268.
35. Cork R, Vaughan R, Humphrey L. Precision and accuracy of the intraoperative monitoring. *Anasth Analg*. 1983;62:211-214.
36. Giuliano K, Scott S, Elliot S, Giuliano A. Temperature measurement in critically ill oral intubated adults: a comparison of pulmonary artery core, tympanic, and oral methods. *Crit Care Med*. 1999;27:2188-2193.
37. Ronneberg K, Roberts WO, McBean AD, Center BA. Temporal artery temperature measurements do not detect hyperthermic marathon runners. *Med Sci Sports Exerc*. 2008;40:1373-1375.
38. Carroll D, Finn C, Judge B, Gill S, Sawyer J. A comparison of measurements from a temporal artery thermometer and a pulmonary artery catheter thermister. *Am J Crit Care*. 2004;13(3):258.
39. Craig J, Lancaster G, Williamson P, Smyth R. Temperature measured at the axilla compared with rectum in children and young people: systematic review. *BMJ*. 2000;320:1174-1178.
40. Morley C, Hewson P, Thornton A, Cole T. Axillary and rectal temperature measurements in infants. *Arch Dis Child*. 1992;67:122-125.
41. Erickson R, Kirklín S. Comparison of ear-based, bladder, oral, and axillary methods for core temperature measurement. *Crit Care Med*. 1993;21:1528-1534.
42. Barras D. A comparison of rectal and axillary temperature by electronic thermometer: measurement in preschool children. *Pediatr Nurs*. 1983;9:424-425.
43. Eoff M, Meir R, Miller C. Temperature measurement in infants. *Nurs Res*. 1974;23:457-460.
44. Anagnostakis D, Matsaniotis N, Grafakos S, Sarafidou E. Rectal-axillary temperature difference in febrile and afebrile infants and children. *Clin Pediatr*. 1993;32:268-272.
45. Muma B. Comparison of rectal, axillary, and tympanic membrane temperature in infant and young children. *Ann Emerg Med*. 1991;20:41-44.
46. Hooper V, Andrews J. Accuracy of noninvasive core temperature measurement in acutely ill adults: the state of the science. *Biol Res Nurs*. 2006;8(1):24-34.
47. Moen J, Chapman S, Sheehan A, Carter P. Axillary versus rectal temperatures in preterm infants under radiant warmers. *J Obstet Gynecol Neonatal Nurs*. 1987; 16:348-352.